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CURRENT HARMONICS REDUCTION OF NON-LINEAR LOAD BY USING AN OPTIMAL CONTROLLER FOR ACTIVE POWER FILTER

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ABSTRACT

The increase of the harmonics disturbance in the ac mains currents has become a major concern due to the wide spread of power electronics equipment in modern electrical systems. This paper presents the analysis and simulation of a three-phase active power filter (APF) compensating the harmonics and reactive power created by nonlinear in steady state and in transients using Matlab Simulink. An optimal control strategy for shunt active filter which is proposed in this paper, based on voltage source inverter using Modified Synchronous reference frame theory (SRF) and sinusoidal pulse width modulation (SPWM) Control. The target of this strategy is to improve the behavior of source current when it is crossing from zero. It is seen that the APF has effectively mitigate the Total Harmonic Distortion (THD). The FFT analysis of the active filter system brings the THD of the source current less than 5% into compliance with IEEE-519 harmonic standards.

KEYWORDS: Total Harmonic Distortion (THD), PWM, PI, Particle swarm optimization.

INTRODUCTION

In the recent decade, the progresses in the manufacturing technology of power electronic elements such as IGBT, GTO and MOSFET as well as microprocessors (digital controllers) have increased the use of real power filters for the reduction of harmonics in voltage and currents (Irannezhad et al., 2012). The term active filter is a common one and is applied to a group of power-electronic circuits incorporating power- switching devices and passive energy-storage-circuit elements, such as inductors and capacitors. The functions of these circuits vary depending on the applications.

They are generally used for controlling current harmonics in supply networks at the low- to medium-voltage distribution level or for reactive power and/or voltage control at high-voltage-distribution level (El-Habrouk, 2000). The main resources that produce harmonics in network, are rectifiers, arc lamps, inductive stove, and etc. Current harmonics which are produced by nonlinear loads change to voltage harmonics while crossing grid impedance. These current and voltage harmonics in network not only have economic drawback but also damage devices and disturb their performance (Yarahmadi et al., 2013). The distorted voltage waveform causes harmonic currents to be drawn by other loads connected at the point of common coupling (PCC). The existence of voltage and current harmonics in power systems decreases the power factor, increases losses in the lines, and can cause timing errors in sensitive electronic equipment (Ucar et al., 2008).Harmonics decline the power system performance and create conditions for equipment destroy. As a consequence, there is a stimulant for end users and utilities to limit harmonics.IEEE Standard 519 proposes to limit the amount of harmonics an end user can inject into the power system so the resulting voltage distortion falls within specified limits (IEEE Std. 519, 1992). Traditionally harmonic distortion has been deal with by the use of passive LC filters. However, the application of passive filters for harmonic reduction may result in poor flexibility for dynamic compensation of different frequency harmonic components and parallel resonances with the network impedance, over compensation of reactive power at fundamental frequency (Priya et al., 2014). So another viable solution is the Active filters. Active filters works on the principle of generating actively a harmonic current spectrum in opposition of the phase to the distorting harmonic current (Bangia et al., 2012). Among different types of Active filters this paper deals with shunt active filter .The present research work emphasis on the application of Particle Swarm Optimization (PSO) to design the optimal gains for PI controller. A Particle Swarm Optimization (PSO) algorithm is proposed to calculate the optimal values of the controller parameters. The Proposed controller is self-adapting, fast and simple in architecture and it can be successfully applied for harmonic filtering under various power system operating conditions (Dubey et al., 2013).

SHUNT ACTIVE FILTER

The shunt active power filter (APF) is a device that is connected in parallel to cancel the harmonic and reactive currents from a nonlinear load. The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line (Kale et al., 2005). Active filter is responsible for providing harmonics and reactive current of load. If it does well source current is sinusoidal and in phase with source voltage (Yarahmadi, 2013). The concept of Shunt Active Filtering was first introduced by Gyugyi and Strycula in 1976(Irannezhad et al., 2012). Nowadays, a Shunt Active Filter is not a dream but a reality, and many SAFs are in commercial operation all over the world. Fig. 1 shows the block diagram of shunt active filter. The simulated active filter is made of a three-phase power supply, a nonlinear load, a PWM inverter, and a PI controller. The controllers of the Active Filters determine in real time the compensating current reference, and force the power converter to synthesize it accurately (Priya et al., 2014). Controller parameters, K_P and K_I of a DC-link PI-controller based on Particle Swarm Optimization (PSO) .The PSO algorithm needs an objective function (OF) to minimize which is a vital criterion for the PSO performance. This means that the PSO algorithm tries to obtain the controller coefficients (K_P , K_I) by minimizing the objective function (Fereidouni et al., 2014).

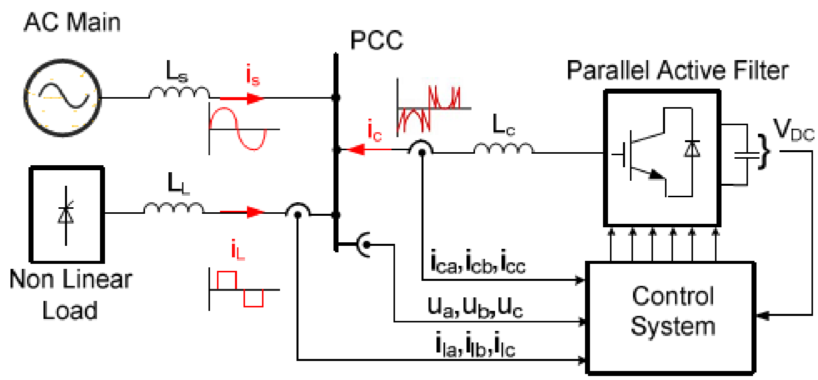


Figure 1: Basic System Configuration for shunt active filter.

Modified Synchronous Reference Frame

The Modified Synchronous Reference Frame method is presented. It is also called the instantaneous current component (*idq*) method (Zaveri et al., 2011). In this method the currents ic_i are obtained from the instantaneous active and reactive current components il_d and il_q of the nonlinear load (da Silva et al., 2010). The mains voltages vi and the il_i polluted currents in αβ components must be calculated as in (1) and (2). The compensation currents may be calculated by (3). However, the *dq* load current components are derived from a synchronous reference frame based on the Park transformation (Zaveri et al., 2011), where θ represents the instantaneous voltage vector angle (4)

$$\begin{bmatrix} v_\propto \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} il_\propto \\ il_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} il_1 \\ il_2 \\ il_3 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} ic_1 \\ ic_2 \\ ic_3 \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}^T \cdot \begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \cdot \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} \quad ,\theta = tan^{-1}\frac{v_\beta}{v_\alpha} \tag{4}$$

With transformation (4) the direct voltage component is:

$$|\overline{v}_{dq}| = |\overline{v}_{\alpha\beta}| = \sqrt{v_\propto^2 + v_\beta^2} \tag{5}$$

and the quadrature voltage component is always null, vq=0 ,so due to geometric relations (4) becomes

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \frac{1}{\sqrt{v_\propto + v_\beta}} \cdot \begin{bmatrix} v_\propto & v_\beta \\ -v_\beta & v_\propto \end{bmatrix} \cdot \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} \quad (6)$$

Instantaneous active and reactive load currents il_d and il_q can also be decomposed into oscillatory and average terms $il_d = \widetilde{il}_d + Il_d$, and$il_q = \widetilde{il}_q + Il_q$. The first harmonic current of positive sequence is transformed to dc quantities, il^{+}_{dq1h} , i.e., this constitutes the average current components. All higher order current harmonics including the first harmonic current of negative sequence, $il^{\pm}_{dqnh+}il^{-}_{dq1h}$, are transformed to non-dc quantities and undergo a frequency shift in the spectra, and so, constitute the oscillatory current components. Eliminating the average current components by HPF's the currents that should be compensated are obtained, $ic_d = -\widetilde{il}_d$ and $ic_q = -\widetilde{il}_q$ .Finally, (7) and (3) calculate the converter currents in the system coordinates. Fig. 2 depicts the voltage and current space vectors in the stationary (αβ) and rotating frames (dq) (Soares, 2000).

$$\begin{bmatrix} ic_\propto \\ ic_\beta \end{bmatrix} = \frac{1}{\sqrt{v_\propto^2 + v_\beta^2}} \cdot \begin{bmatrix} v_\propto & -v_\beta \\ v_\beta & v_\propto \end{bmatrix} \cdot \begin{bmatrix} ic_d \\ ic_q \end{bmatrix} \quad (7)$$

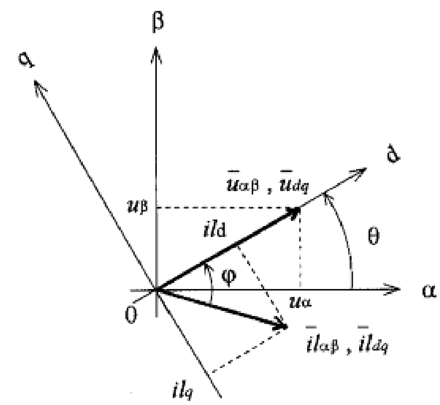


Figure 2: Voltage and current space vectors in the stationary and synchronous reference frames.

Sinusoidal Pulse Width Modulation (SPWM) Control

The most simple and well known PWM technique is the sinusoidal PWM as shown in Fig. 3. This technique uses a controller which determines the voltage reference of the inverter from the error between the measured current and its reference. This reference voltage is then compared with a triangular carrier signal (with high frequency defining the switching frequency). The output of this comparison gives the switching function of the VSI. With this technique, the effect of equivalent high switching frequency converter is obtained with low switching frequency converter. It is very promising in current-source APF that adopt superconducting magnetic energy storage component (Wang et al., 2004). The choice of the ratio between the frequency of the reference signal and the frequency of the carrier signal is very important in the case of symmetric and periodic reference. As a consequence, in the case of sinusoidal reference, the ratio between the two frequencies must be integer to synchronize the carrier with the reference. Over more, it is preferable that the carrier frequency be odd to conserve the reference symmetry. In all cases this ratio must be sufficiently high to ensure the fast switching (Purnima et al., 2014) and to take the switching harmonics away from the fundamental produced by the inverter.

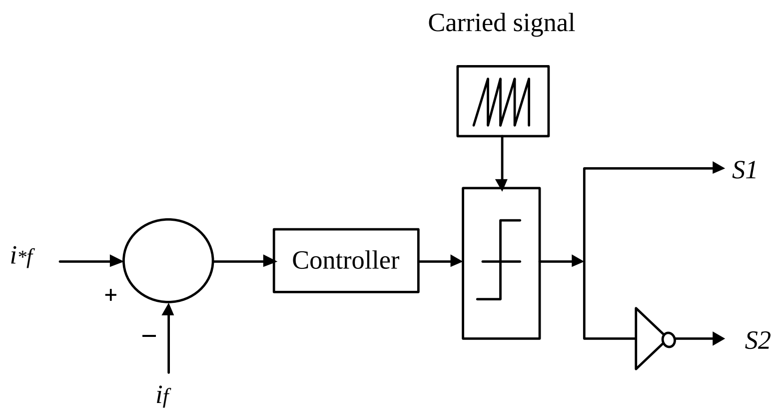


Figure 3: The principle of sinusoidal PWM control method

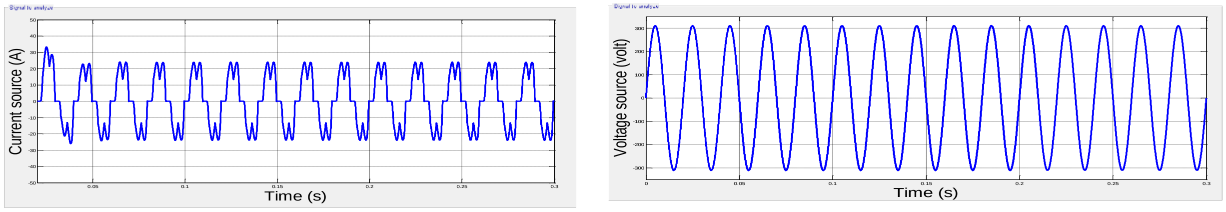
SIMULATIONS AND RESULTS

In this work MATLAB/SIMULINK is used as a simulation tool to implement the proposed active filter and study the operation of the active power filter under different operating conditions. The parameters of system are shown in Table 1.

Table1: Parameters of the System

Supply phase voltage (*RMS*)	220 V
Supply frequency f_s	50 Hz
Line inductor L_L	0.003 H
Filter inductor L_f	0.0009 H
DC link capacitor C_1, C_2	1000 µF
DC link capacitor Voltage V_{DC}	620 V
Switching frequency f_{sw}	10 KHz
Load rectifier bridge	25 Ω,65 mH

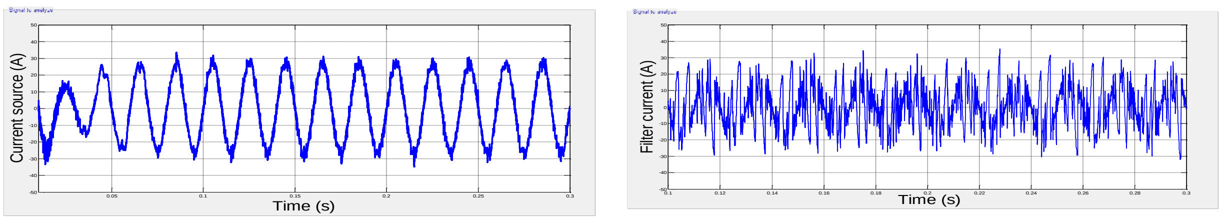
The purpose of the designed case studies is to show the validity and performance of the proposed APF control strategy, even if the mains voltages are highly distorted. The DC Voltage Control regulator block uses a PI regulator. Proportional and integral factors of PI controller tuning by PSO are K_P=0.1226 and K_I=30.8782 respectively. The difference between the DC sides voltages (positive and negative) are controlled to keep the DC side bridge balanced in steady-state. Small deviations between the voltages may occur at changes of active/reactive converter current or due to nonlinearity on lack of precision in the execution of the pulse width modulated bridge voltage. Fig. 4(a) shows source current without shunt active filter and Fig. 4(b) shows source voltage. Due to the presence of the nonlinear load, so the current waveform is in distorted manner.



(a) (b)

Figure 4: (a): source current without shunt active filter, (b): source voltage.

Fig. 5, (a) shows the sinusoidal waveform of the source current after connected APF with PI-PSO control and (b) represented the filter compensating current.



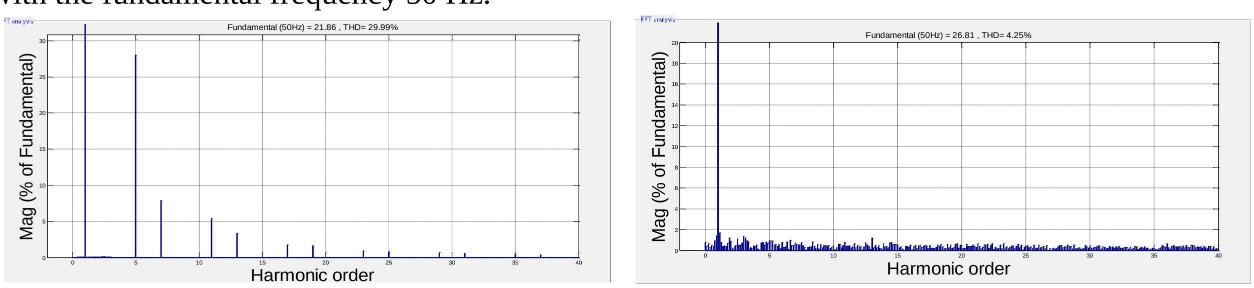
(a)

(b)

Figure 5: (a): Source current with shunt active filter, (b): Filter current.

According to Figure up by using this control method, source current is improved while crossing zero and THD is reduced from 29.9% to 4.2%.As shown, the application of active filter removes the harmonics of the current and the source current synchronizes with the voltage.

Fig. 6 shows the harmonic spectrum of the source current before applying the filter and after applying the filter. The Fast Fourier Transform (FFT) is used to measure the order of harmonics with the fundamental frequency 50 Hz.



(a) (b)

Figure 6: The harmonic spectrum of the source current: (a) Before applying the filter (b): After applying the filter.

To show the efficiency of control method in the transient state, the load resistance at the instant of 0.5 second is increased by 5000W. Figure 7 shows the different waves during the changes of load. The AC Current Control block tracks the current reference vector ("*d*" and "*q*" components) with a feed forward scheme to achieve a fast control of the current at load changes and disturbances.

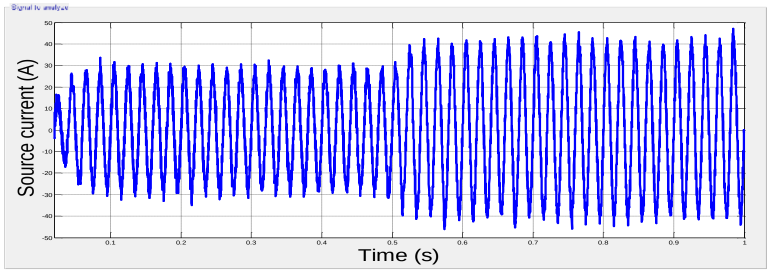
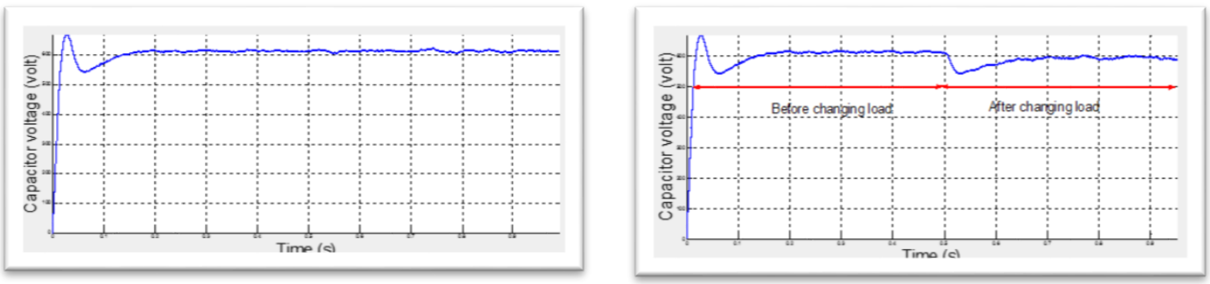


Fig. 7: Source current during load change.

The PI-PSO controller maintains the DC-side capacitor voltage constant that shown in Fig. 8. The analysis of the results show that the working of the active filter is very satisfied to compensate the harmonics and reactive power even under transient and distorted conditions of distribution supply.



(a) (b)

Figure 8: (a): Capacitor voltage in steady-state case, (b): Capacitor voltage after changing load.

Fig. 9 shows the order of harmonics which are plotted under nonlinear load with steady state and with transient state conditions.

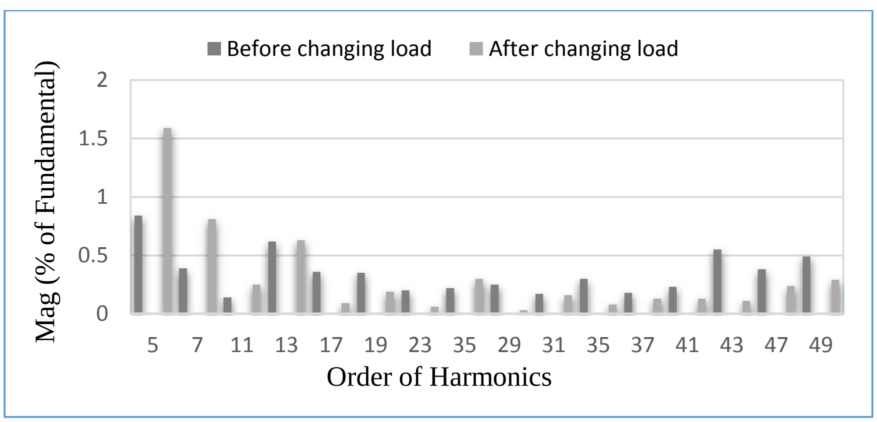


Figure 9: Harmonics plotted for the fundamental due to the load variation.

CONCLUSIONS

In this paper a current control method used in a three-phase parallel active filter, which is able to improve the quality of power, is introduced using Modified Synchronous Reference Frame theory with Sinusoidal Pulse Width Modulation (SPWM) Control. The performance of the shunt active power filter is investigated under different scenarios. This paper simulates an APF equipped with

PI-PSO to effectively control the dc bus voltage and improve the steady state and transient performances. The applied control method behaves well in terms of steady and transient responses. THD of the source current after compensation is synchronous with the value determined by IEEE-519 and is under 5%.

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